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## Faculty Working Papers

THE EFFECT OF POPULATION GROWTH ON  
AGRICULTURAL SAVING IN IRRIGATION

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#156

**College of Commerce and Business Administration  
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FACULTY WORKING PAPERS

College of Commerce and Business Administration

University of Illinois at Urbana-Champaign

January 22, 1974

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The Effect of Population Growth on Agricultural  
Saving in Irrigation\*

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INTRODUCTION

Models of population and economic growth (e.g., Coale and Hoover, 1958) commonly assume that, *ceteris paribus*, higher fertility means lower savings. The available data seem to support this assumption, notably that of Leff (1969).

Leff's study has little bearing upon the relationship of population growth to agricultural investment in less-developed countries (LDC's), however. Much agricultural investment is non-monetized, and the national accounting data used by Leff refer only to monetized investment. Furthermore, much of the agricultural investment that is paid for in money is omitted from many national accounts. Both of these omissions are shown by the capital/output ratios suggested for agriculture by the national accounts of India and other LDC's, e.g., 1.5 (Manne in Tinbergen, 1967, Appendix E) and 0.9 (Reddaway in Myint, 1964, p. 97).<sup>1</sup> In contrast, the survey data for all LDC's now and in earlier years show that the capital/output ratio at contemporary valuations<sup>2</sup> is upward of 4.

Given that agricultural output represents perhaps half of a poor LDC's total product, and given that (contrary to the common opinion) the rate of investment

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\*I am grateful to Professors Bryan Boulier, Volke Doving, Bert F. Hoselitz, and Nathaniel Leff for helpful comments, and to Professor Chester Baker for discussion of this topic.

<sup>1</sup>Part of the explanation of these low ratios is that frequently only one small part of private-sector agricultural capital is included in the national-income-accounts, the agricultural equipment which is imported into the country (Hooley, 1967; Rozenhal, 1970). I am grateful to Nathaniel Leff for bringing Hooley's work to my attention.

<sup>2</sup>For China (Buck, 1930, pp. 65-66), a capital/output ratio of 4.65. For India, see the Studies in Farm Management series, e.g., Orissa, 4.3 (1958-59, pp. 25 and 29); Punjab, 4.3 (1955-56, pp. 28 and 56); Andhra Pradesh, 6.4 (1968, p. 174). For a host of data on westernized countries see Clark (1957, p. 637).



in LDC agriculture is quite respectable compared to the industrial sector,<sup>3</sup> if population growth has a positive effect on saving agriculture it might be great enough to rival any negative effect outside of agriculture. For this reason, as well as because of the intrinsic importance of the agricultural sector, the effect of population growth upon agricultural investment needs to be known if sound policy decisions about population are to be made.

No body of contemporary farm-household survey data known to me will support an analysis of the relationship of family fertility and size to family farm investment. But data on investment in irrigation in various countries offer some basis for understanding the relationship of population growth to agricultural investment. This paper, therefore, proceeds to explore the data on irrigation and population density. Afterwards some historical data on land use and population growth are adduced for several countries to buttress the conclusion drawn from the irrigation data.

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<sup>3</sup>After reviewing the evidence from surveys of Indian agriculture, Roselitz summarizes that "additions to productive capital invested in agriculture amount to more than 8% of total (including non-cash) income," and if durable goods such as housing are included, "total investment...may be assumed to reach a magnitude of 10% or even 12% of total income" (1964, p. 357). During the same years, net fixed monetised investment in India ran around 6-7% (Coale and Hoover, 1958, p. 149), with gross investment a somewhat higher percentage.



A CROSS-SECTIONAL STUDY OF POPULATION GROWTH /  
EFFECTS ON IRRIGATION INVESTMENT

It is reasonable to think of the building of an irrigation system as a response to these two conditions: a) increased demand for food over the previous period; b) new land sufficiently scarce so that the cost of clearing it is higher than the cost of building an irrigation system to produce the same amount of additional output. High population density per acre of cultivated land would seem to indicate the presence of condition (b); if there were more easily-cultivable land available, people would clear it and the density would be lower. The comparison of two countries with different population densities may be seen as a proxy for changes in the same country at two stages of population increase. Therefore, the relationship between i) population density per acre of cultivated land, and ii) the proportion of the cultivated land that people have irrigated, may be taken as a measure of the effect of population increase on the amount of investment in irrigation.

The necessary data were collected by the President's Commission on the World Food Problem (U.S., 1967, Vol. II, pp. 441-442). The simplest approach is the regression of the proportion<sup>4</sup> of cultivated land that is irrigated (I/C) with respect to the population per unit of cultivated land (P/C),

$$I/C = a + b_1 (P/C) \quad \dots(1)$$

The logic is that P/C is the best measure of population density with respect to agricultural production; when considering agricultural production it is reasonable that land that is uncultivable because it is mountain or desert should be removed

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<sup>4</sup>There would seem to be no problem of spurious correlation here. "The question of spurious correlation quite obviously does not arise when the hypothesis to be tested has initially been formulated in terms of ratios..." (Kuh and Meyer, 1955, p. 401). The relationship of interest here is the effect of population density to the proportion of irrigated land, for which the ratios in the regression are the appropriate proxies.



from the comparison of the various countries. The results of this simple regression for the 48 countries in the pooled sample, for the 18 Asian countries alone, and for the 19 South American countries alone, are shown in lines 1-3 of the table. In the pooled sample the independent variable has a t ratio of 4.3, and explains 29% of the variance ( $r^2 = .29$ ). The separate Asian and South America samples have coefficients of the same general order as each other and as the sample as a whole, which lends support to the meaningfulness of the several relationships.

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Table near here  
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A second approach is to characterize the variables as logarithms,

$$\log(I/C) = a + b_1 \log(P/C), \quad \dots(2)$$

The unstandardized regression coefficients may be interpreted as elasticities; the elasticity for the pooled sample is 2.72, and the separate Asian and South America estimates are a bit lower (lines 4-6 in the table).

To allow for geographical differences, but at the same time to take statistical advantage of the entire sample, dummy variables for Asia and South America were used in two ways. The first of these was with additive dummies, in the linear form

$$I/C = a + b_1(P/C) + d_1 D_1 + d_2 D_2 \quad \dots(3)$$

where  $D_1$  is the dummy for Asia and  $D_2$  the dummy for South America; and in the logarithmic form

$$\log I/C = a + b_1 \log(P/C) + d_1 \log(D_1) + d_2 \log(D_2) \quad \dots(4)$$

The second geographical-allowance regression employs interactive dummies, linearly

$$I/C = a + b_1(P/C) + d_1 D_1(P/C) + d_2 D_2(P/C) \quad \dots(5)$$



and in the logarithmic form

$$\log (I/C) = a + b_1 \log (P/C) + d_1 \log D_1 (P/C) + d_2 \log D_2 (P/C) \quad \dots (6)$$

As lines 7-10 show, the  $R^2$  is raised considerably by the addition of the dummies. But the size of the coefficient of P/C is raised only insignificantly, except with the interactive dummies in the interactive form. This suggests that there is indeed a geographical effect, especially with respect to South America. (The negative Asian effect in line 9 does not make sense, and therefore the Asian effect in lines 7, 8, and 10 will be taken as the more reasonable.) But the inclusion of the geographical allowance does not alter the magnitude of the effect of P/C upon I/C.

It is reasonable that there is some relationship between the quantity of arable land available for cultivation, and the amount of investment in irrigation: if people can cultivate additional land, they are less likely to irrigate. This might affect the statistical relationship seen in regressions containing only P/C as a substantive variable. Therefore a variable for cultivated land as a proportion of total land (C/T) was added to the linear regression

$$I/C = a + b_1 (P/C) + b_2 (C/T) \quad \dots (7)$$

and to the logarithmic regression

$$\log (I/C) = a + b_1 \log (P/C) + b_2 \log (C/T). \quad \dots (8)$$

The results in lines 11-16 show that the coefficients of P/C are not changed much by the addition of C/T. This suggests that the relationship between I/C and P/C is not a proxy for a relationship of one or the other with C/T, which strengthens belief in the relationship between population density and investment in irrigation. The coefficient for C/T does have the expected negative sign, which is interesting, but the strength of its relationship to investment in irrigation does not seem to be very great.



The level of economic development of a society is intertwined in all sorts of relationships because of the all-pervasiveness of the development process. Therefore fishing-expedition regressions were run with per-capita income (Y/P) as an additional argument,

$$I/C = a_1 + b_1 (P/C) + b_2 (Y/P). \quad \dots(9)$$

Lines 17-19 of the table show that the addition of Y/P does not alter the relationship between I/C and P/C, and the effect of Y/P itself is insignificantly (and surprisingly) small.\*

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\*The socialist countries Poland, Yugoslavia, China, Cuba, and USSR were omitted from the sample for lack of data on Y/P. As a check, the same reduced sample was run on the basic regressions 1 and 2. The results are much the same as the results with the full sample.

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Now a last and somewhat-confusing line of inquiry. Exploratory regressions were run with population per unit of total land (P/T) as an additional argument, linearly,

$$I/C = a + b_1 (P/C) + b_2 (P/T), \quad \dots(10)$$

and in the logarithmic form

$$\log (I/C) = a + b_1 \log (P/C) + b_2 \log (P/T). \quad \dots(11)$$

P/T appears to have a significant negative impact on I/C (lines 20-22), though in the log form the effect is much smaller (lines 23-25). The negative sign is puzzling. A possible partial explanation is that P/T is to some extent a proxy



for C/T, the correlation between them is high, as seen in lines 32-34. (That relationship would seem to be causal in both directions.) But when C/T is added as an independent variable, the effect of P/T is only made more negative except in Asia, where the effect becomes positive (lines 26-31).

Further investigation would be needed to clarify the roles of P/T and C/T. But given that the inclusion of P/T and C/T do not much change the effect of P/C upon I/C, the subject need not be pursued here.

To summarize the empirical work up to here: Taken as a whole, the results of the regressions with arguments additional to P/C do not much affect the relationship between P/C and I/C; this may be seen by glancing down columns 5 and 6. These strengthen belief that the effect of population density upon investment in irrigation is what it seems to be.

#### DISCUSSION OF POPULATION-IRRIGATION RELATIONSHIP

The reader may question whether the line of causality also runs from investments in irrigation to population density. Indeed, in some cases governments have undertaken large-scale irrigation projects in barren areas, and population settlement has followed. But such government irrigation projects are for the purpose of domestic resettlement. They influence population distribution-- that is, population densities in various parts of a country. But given the reasonable assumption that the irrigation project does not affect national fertility or international migration, density for the country as a whole is not affected by such a project. Hence we may dismiss the possibility that these data show causality running from irrigation to density. This strengthens the case for believing that the data reflect causality running from population density to irrigation intensity.

It should be interesting to translate the statistical estimates into economic magnitudes. Let us take as our best estimate for the effect of P/C the



regression coefficient in model 2, which may be interpreted directly as an elasticity; it is 2.7 for the sample as a whole (line 4). Given that in the average country in the sample 18.4% of cultivated land is irrigated, an increase in population density of 10% would produce an increase of  $(.10 \times 2.7 \times .184) = 4.8\%$  in the stock of irrigated land. And given that irrigated land can increase output per acre by a factor of two or more, it is apparent that this mechanism can have a very important role in adjusting food supply to population increase--perhaps taking up the whole slack in a representative country in our sample. And when considering the overall quantitative impact of P/C upon I/C, it should be remembered that measurement error in either of the variables biases the coefficient downwards. And there is surely considerable measurement error in both the variables. Therefore, the effect is surely greater than the coefficients suggest. And it is reasonable that population density also has a positive effect on other aspects of agricultural capital formation such as land clearing, which increases the total response to be expected.\*

Given the substantial difficulties--the coverage of the national-income data, the difference in rates of depreciation, the relative values of agricultural and non-agricultural capital, and the questionable specification of the models--it does not seem worthwhile to push forward with a quantitative comparison of the .87 population-growth elasticity for irrigation systems against Leff's -.54

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\*Gross investment over time can be smaller in agriculture than in other sectors and yet agricultural capital still be as large or larger than non-agricultural capital. This is because physical depreciation of investments in land improvement is far slower than in industrial equipment, especially if upkeep is properly figured. A truck or a soap plant or an electric power station has a far shorter life than does an irrigation system. Stone dams built by the Nabateans in Israel's Negev almost 2,000 years ago are still used by the Bedouin (who themselves build only mud dams). Roman roads are still in use. Underground irrigation qanats in Iran still carry water a thousand or more years after construction. And stone-clearing from a field continues to yield returns literally indefinitely.



elasticity of national-income savings.<sup>5</sup> The issue of which influence on total saving is greater--that is, whether the overall effect of population growth on saving is positive or negative--should be considered an open question.

#### HISTORICAL DATA ON POPULATION GROWTH AND LAND LEARNING

Irrigation of land is only part of total investment in land. Therefore, it would seem useful to learn more about the relationship of population density to other aspects of land investment. Land clearing is the most important of these other aspects, and therefore there now follows all that I have been able to glean of historical data on the relationship of population growth to land clearing. These data yield a picture which supports the above work on irrigation investment, and therefore should make the irrigation results more satisfying and persuasive.

(1) In the late 18th century and the first half of the 19th century in Ireland--the period of very rapid population growth--the peasants invested great amounts of labor in new lands, even against the obstacle that they did not even own the land they invested in. "The peasant and his children were driven to such arduous and unrewarding work by the two forces which give their distinctive character to many of the institutions of the Irish countryside--the pressure of population and the landlords' demand for ever-increasing rents" (Connell, 1965, pp. 430-431). Over the decade from 1841 to 1851 the amount of cultivated land increased by 10%, though even at the height of the population increase before the famine starting in 1845 population only increased by a decadal rate of 5.3% (Connell, 1965, p. 423). This suggests that rural investment was enough to

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<sup>5</sup>The elasticity of savings with respect to child dependents, who constitute 40-46% (say 43%) of the populations in his LDC's is -1.3. A 1% increase in dependents implies a 43% increase in population. Hence, a 1% increase in population produces  $(-1.3 \times .43) = .56\%$  decrease in non-agricultural savings.



account for all--and even more--of the increase in total food product required by population growth during those years.

(2) From 1400 to 1957 the cultivated acreage in China expanded fourfold--plus from 25 million hectares to 112 million hectares (Perkins, 1969, p. 240). This increase in cultivated land apparently accounted for more than half of the increase in grain output that sustained the living standard of the eight-fold-plus increase in population over the same period. And investment in water-control systems and terracing accounted for much of the rest of the increase in output. "Only a small share of the rise in yields can be explained by improvements in the 'traditional' technology" (Perkins, 1969, p. 77).

(3) The rapid population growth in India in recent decades has been accompanied by fairly rapid increase in agricultural investment. The earlier-quoted survey data mustered by Rosditz constitute one piece of evidence; with a capital/output ratio of 4, an investment rate of 12% is by itself just about sufficient to sustain a population growing at 3% per year.

Other evidence comes from data on land improvement. In the village of Senapur, studied in 1954 by Hopper and in 1964 by S. Simon, the Agricultural class increased their agricultural income considerably over the period. And: "The increase in agricultural income derives primarily from the greater amount of acreage that is cultivated. The Noniyas, traditionally an earth-working class, have in the past reclaimed large areas of previously worthless, saline land through extremely laborious methods" (S. Simon, 1968, p. 313). For India as a whole, over the period 1949-50 to 1960-61 irrigated land increased by 25%, from a tenth to a fifth of all cultivated land. And the total area of all cultivated land increased about 10% (Cole and Mellor, 1964).

(4) In the previous examples the investment was largely direct and non-monetized. The same mechanism can also operate in non-subsistence agricultural



sectors of LDC's, though in a bit more complex manner, through the increased market demand for food caused by the rise in population. Slicher van Bath (1963, Part III B1) documents the close relationship between population, food prices, and land reclamation in Europe from 1500 to 1900; when population grew at a fast rate, food prices were high, and land creation increased.

"The higher cereal prices after 1756 stimulated agricultural development. . . . Around Poitiers the area of reclaimed land was usually either 20 to 25 acres or about 2 hectares. In the former case the reclamation was the work of a day-labourer for a whole winter, in the latter that of a farmer with a team of oxen" (Slicher van Bath, 1963, p. 231).

(5) In Taiwan from 1905 until 1930, total acreage increased about 30%, almost as fast as population increased. When later from 1930 to 1960 there was little new land to develop, more land was irrigated, an increase of about 59% over the period. At the same time, the crop area was increased by multiple cropping, and the use of fertilizers allowed total productivity to continue rising at a very rapid rate (Ho, 1966, pp. 50-51).

(6) Taken together, what do these historical data show? They show that in LDC's increased investment in land accounts for most of the long-run increase in agricultural output. And agricultural output in the long run kept up with population increase. One might wonder whether the increase in land investment was really caused by the population growth. This question might have some validity in recent decades. But it does not apply to the long history of, say, China; in its nonmarket economy, there was no motive for increasing food production other than an increase in size in one's family or village. Hence it is reasonable to assume that increased population caused the added investment in agriculture.

#### SUMMARY

Cross-national regressions of irrigation as a function of population density on cultivated land area show a strong positive effect. The



results in the simple regressions are buttressed by the results of regressions that include as independent variables the cultivated area as a proportion of the total area, per capita income, geographical dummies, and the population density with respect to the country's entire land area; the effect of population density on cultivated land is somewhat strengthened rather than weakened by the addition of these other variables, which increases confidence in the basic observed relationship. Support also comes from historical data which suggest that population growth induces land clearing in LDC agriculture.

The elasticity of the irrigated area with respect to population density on cultivated land is .67. It is difficult to compare this positive effect with the negative effect, as observed by Leff, of population growth on monetized savings. The data used here have many shortcomings. And Leff's data and regression specification are open to many sorts of questions also. The data presented here do suggest, however, that the two effects are of somewhat the same order of magnitude and in opposite directions. And the net effect of population growth on total investment in LDC's may be either negative or positive or a trade-off. Much additional work is necessary before writers are entitled to say with any confidence--as they so frequently do--just what is the direction of the net effect of population growth upon total investment. But it does seem clear that the effect upon agricultural investment is positive.



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